

Source Term

ISSUE 5: Under what conditions, if any, should scenario-specific accident source terms be used for licensing decisions regarding containment and site suitability?

BACKGROUND:

Current light-water reactors (LWRs) use site-specific parameters (e.g., exclusion area boundary) and a deterministic predetermined source term into containment to analyze the effectiveness of the containment and site suitability for licensing purposes. The LWR deterministic source terms are described in Atomic Energy Commission (AEC) Technical Issue Document 14844 (TID-14844) and Nuclear Regulatory Commission (NRC) NUREG-1465, and represent a bounding fission product release associated with an in-vessel core melt accident in an LWR.

The Fort St. Vrain Nuclear Generating Station (FSV), a large high-temperature gas-cooled reactor (HTGR) which operated from 1974 to 1989, used a deterministic source term based upon TID-14844, which was made conservative by assuming unrestricted core heat up, total loss of forced circulation, and a fission product release rate from the fuel that was much faster than experimental results had shown. At the time FSV was licensed, the trend of the radioactive source term for HTGR siting purposes was to use more conservative releases as the plant size increased.¹

In the late 1980s, the U.S. Department of Energy (DOE) sponsored work on an HTGR design known as the Modular High-Temperature Gas-Cooled Reactor (MHTGR). For this design, DOE had proposed a mechanistic (scenario-specific) source term that was based upon the characteristics of the fuel and plant to determine the magnitude, timing and nature of fission product release from the core. The proposed use of such a source term represented a major departure from both LWRs and earlier high-temperature gas-cooled reactor HTGR designs with respect to containment and siting evaluations. NRC staff stated in NUREG-1338, a 1989 draft safety evaluation report (SER) for the MHTGR, that final acceptance and use of a mechanistic source term was contingent on the satisfactory resolution of technical and policy considerations, and noted that extensive research and testing was needed to address the technical issues.

In SECY-93-092, the staff addressed the source term issue for the PRISM, the MHTGR, the PIUS, and the Canadian Deuterium-Uranium (CANDU 3) reactor designs and recommended to the Commission that mechanistic source terms should be allowed provided that:

¹Fisher, Orvis. *Licensing of HTGRs in the United States*. International Atomic Energy Agency, Vienna (Austria). International Working Group on Gas-Cooled Reactors. Specialists meeting on gas-cooled reactor safety and licensing aspects, Lausanne, Switzerland, 1-3 September 1980. Summary Report Jan 1981. IWGGCR-1, pp: 184-190.

- The reactor and fuel performance under normal and off-normal operating conditions is sufficiently well understood to permit a mechanistic analysis. Sufficient data should exist on the reactor and fuel performance through the research, development, and testing programs to provide the adequate confidence in the mechanistic approach.
- The transport of fission products can be adequately modeled for all barriers and pathways to the environs, including specific consideration of containment design. The calculations should be as realistic as possible so that the values and limitations of any mechanism or barrier are not obscured.
- The events considered in the analyses to develop the set of source terms for each design are selected to bound severe accidents and design-dependent uncertainties.

The Advisory Committee on Reactor Safeguards (ACRS) agreed with the staff, and stated in a letter dated February 19, 1993, to NRC Chairman Selin:

The staff proposal to base the source terms on mechanistic analyses appears reasonable, although it is clear that the present data base will need to be expanded. We note that the staff is now developing for LWRs a revision to the TID-14844 source term. It will be appropriate for the staff to consider using the newer approach when it develops source terms, and to take specific account of the unique features of each of the reactor types.

In a July 30, 1993, SRM, the Commission approved the staff's recommendations, stating: "The Commission approves the staff's recommendations including its agreement with the ACRS."

DISCUSSION:

The source term used in LWR siting evaluations is based on an in-vessel core melt accident in which a large portion of the radionuclide inventory is released early into containment. This may very well not be applicable to non-LWR designs. In the recent non-LWR pre-application activities, the designers propose an approach to source term selection similar to that proposed for the MHTGR for assessing the effectiveness of plant mitigation features or site suitability. This has resulted in proposals to use mechanistic scenario-specific source terms derived from anticipated operating occurrences (AOOs) and design basis events (DBEs) defined for the plant, using phenomenological models of fission product transport. Such mechanistic source terms that would take into account the predicted fuel and plant performance over a wide range of conditions would need to account for uncertainties. Accordingly, it should be emphasized that such an approach will require much research and testing to fully understand and develop technically sound mechanistic source terms. Alternatively, some may consider the use of a licensing source term representative of severe core damage as an element of defense-in-depth and, as such, it should be applied to all reactors.

Using mechanistic source terms based on a selection of design basis events and a good foundation of plant-specific knowledge, such as fuel behavior and core response under off-normal conditions, has been the trend for advanced non-LWRs worldwide. The HTR-10 in China used a source term based on a mechanistic approach in which severe core damage was

not arbitrarily postulated for the siting evaluation; instead the radiation release was calculated specifically for the individual accidents leading to the largest release of radionuclides from the fuel elements. Both Exelon and ESKOM proposed mechanistic source terms based on design basis events and predictions of fuel behavior for the pebble bed modular reactor (PBMR).

At a public workshop held on October 22–23, 2002, participants stated that although a bounding source term is used in the licensing of current LWRs, the regulations do allow for either approach. Workshop participants felt that the regulations should retain the flexibility of allowing the use of either a bounding or scenario-specific source terms. Additionally, some stated that there was no need to modify the Commission decision of 1993.

OPTIONS:

The options considered by the staff in addressing this issue are:

- (a) Use a deterministic bounding source term which is based on the conservative assumption of core damage and fission product release.

This option represents the current practice used on LWRs and is consistent with the view (i.e., defense-in-depth) that siting and containment decisions should be made in consideration of a severe core damage accident. In fact, some may consider the use of a source term representative of severe core damage as an element of defense-in-depth and, as such, it should be applied to all reactors. For non-LWRs this may be highly conservative, not accurately reflecting the design attributes of non-LWRs. Using such a source term could provide a disincentive for designers to develop high quality fuel and emphasize accident prevention.

- (b) Retain prior Commission guidance that allows scenario-specific (mechanistic) source terms based upon understanding fission product behavior and plant conditions and performance.

This option has the benefit of recognizing the unique features of the non-LWR designs. In addition, this option is consistent with previous Commission and ACRS decisions. However, in order to properly determine a mechanistic source term, a large amount of resources will need to be devoted to research and testing to understand plant performance, fuel behavior, and fission product release characteristics over a wide range of conditions.

RECOMMENDATION:

The staff recommends that the Commission take the following action:

- Retain the Commission's guidance contained in the July 30, 1993, SRM that allows the use of scenario-specific source terms, provided there is sufficient understanding and assurance of plant and fuel performance and deterministic engineering judgement is used to bound uncertainties.²

²Note: This represents a fundamental change in practice from that used on LWRs, in that the source term used for siting considerations may not be that associated with a core melt accident.

This recommendation is consistent with Option b above and, if approved by the Commission, would allow credit to be given for the unique aspects of plant design and build upon the scenario specific recommendation under Issue 4. Furthermore, this approach is consistent with prior Commission and ACRS views. However, this approach is also dependent upon understanding fuel and fission product behavior under a wide range of scenarios and on ensuring fuel and plant performance is maintained over the life of the plant. This approach is also very dependent on the event selection process.

For the purpose of siting and containment/confinement decisions, the staff recommends that conservative source terms for AOOs and DBEs be used. For emergency planning purposes a best estimate source term would be acceptable.